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Technical Report ARFSD-TR-90033

INFRARED DETECTORS IN PRECISION GUIDED MUNITIONS

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March 1991

US ARMY
ARMAMENT MUNITIONS
& CHEMICAL COMMAND
ARMAMENT RDE CENTER

U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

Fire Support Armaments Center

Picatinny Arsenal, New Jersey

REPORT DOCUMENTATION PAGE

Form Approved
OMB N0. 0704-0188

1. AGENCY USE ONLY ***(Leave blank)***

2. REPORT DATE
March 1990

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
INFRARED DETECTORS IN PRECISION GUIDED MUNITIONS

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ARDEC, FSAC
Precision Munitions Division (SMCAR-FSP-E)
Picatinny Arsenal, NJ 07806-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report ARFSD-TR-90033

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ARDEC, IMD
STINFO Br
ATTN: SMCAR-IMI-I
Picatinny Arsenal, NJ 07806-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

The infrared sensor system is a very important portion of an infrared precision guided munition. This system detects targets at night, in clutters, and those that can't be seen by the naked eye. Without a very precise detector system, a target will not be detected during the search phase of the munition's flight. Many conditions must be met to produce a detector system that will have a high probability of detecting a target when the munition is fired from the gun. The contents of this report will illustrate these conditions and recommend enhancements to a guided munition detector system that will compensate for weaknesses encountered in infrared detection.

14. SUBJECT TERMS

Detector types	Dome characteristics	Atmospheric properties
System enhancements	Infrared background	

15. NUMBER OF PAGES
16

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-1 298-102

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INTRODUCTION

Defeating the enemy quickly and effectively, while minimizing casualties to one's own troops, are among the primary concerns in combat situations. Precision guided munitions (PGM) are used to aid in achieving these objectives. PGM are highly sophisticated weapons used for both attacking the enemy and defending one's own troops. By implementing state of the art technology in munitions, enemy vehicles can be effectively destroyed by firing a minimal number of rounds. On board the PGM is a highly sophisticated electromechanical system that detects targets during the munitions flight and maneuvers the munitions to impact the target. Impacting the target is made easier through the use of guided munitions than by the upguided munition or "dumb" munition.

By using guided munitions in combat, the user has a greater chance of destroying enemy targets than through the use of conventional "dumb" munitions which are shells that do not contain any type of guidance system within them. Their chances of striking the target depends primarily upon calculations made prior to firing the gun. If the first shell misses the target, the gun aimpoint is adjusted (both azimuth and elevation) to prepare for the next shot. The aiming of the gun is determined by making calculations based upon comparing the displacement of the impact of the previous shell fired with respect to the target's position. This method has many drawbacks. A miss can occur on the second, third, or fourth shot if the target has moved. Other deterrents are due to changes in wind direction, or quantity of propellant loaded in the shell which, in turn, would thrust the shell a greater or lesser distance than the previous shot.

In the case of a guided munition, the PGM is fired as close to the suspected target as possible and forgotten. The PGM is referred to as a fire-and-forget munition because of it's ability to destroy targets with a high kill probability. The reliability of the munition provides the soldier with great confidence that the target will be destroyed, thus allowing him to search for other potential targets.

On board the munition is a guidance system that seeks, acquires, and maneuvers the projectile to impact the target. The signal processor within the sensor system makes it possible to detect targets in clutter and ground cover while avoiding decoys. However, this component is expensive so it must be designed and developed in such a manner that every shot from the gun has a high probability of impacting the target.

With this technology, the enemy can be destroyed more rapidly and effectively than by the conventional means. By minimizing the time taken to destroy enemy targets, the time the enemy has to retaliate and the number of rounds fired are reduced. By implementing infrared sensors into PGM, state of the art performance is attainable for both offensive attacks and defensive countermeasures.

The infrared sensor operates in a passive mode which means that it uses energy emitted by the target for tracking the target or uses energy originating from natural sources that is reflected by the target. This system also operates by viewing the contrast in emitted between the target and its surrounding background. Objects can exchange energy by three means: conduction, convection, and radiation. The basis for using infrared detectors is that all objects emitting a temperature above absolute zero can be detected. With an infrared detector operating as a thermometer, it can see targets that the human eye cannot. This process, however, is much more complex than it appears. When the source emits thermal radiation, it passes through the atmosphere before arriving at the detector. While in the atmosphere, the radiation can be scattered, refracted, reflected, absorbed, or diffracted which can make it very difficult for the detector to obtain the proper information pertaining to target detection.

This report will explain some pertinent criteria that infrared sensors must meet in order to detect targets. The application of infrared sensors in guided munitions is the main theme of this report. However, infrared sensors serve many other applications in both industry and military (as smoke detectors in fire alarms and as enemy missile detectors for military aircraft).

BACKGROUND

In the electromagnetic spectrum (fig. 1), the wavelength of infrared radiation is longer than that of visible light, but is shorter than radio waves. The unit of measure of the infrared wavelength is the micron (one millionth of a meter), and its range extends from 0.75 microns to 1000 microns. This range is often divided into four regions.

Range (microns)	Region
0.75 to 1.5	Near infrared
1.5 to 10	Intermediate infrared
10 to 300	Far infrared
300 to 1000	Submillimeter infrared

The infrared detector acts as a radiation thermometer that detects the surface temperature of an object without actually touching it. Since every object, having a temperature above absolute zero (-273°C), emits radiant energy, infrared detector serves as a practical means of sensing targets that the human eye is not capable of seeing especially at night. Radiation from the object and its distribution with wavelength depends on the temperature and emissivity of the body. Emissivity is the ratio of the actual emission from the body to that from a hypothetical source called "blackbody" at

the same temperature and is dependent upon the body composition of the substance, wavelength, surface condition (both physical and chemical), direction from the normal, and temperature of the body. A blackbody is an ideal thermal radiator where the emitted power is a maximum for a perfect absorber. Therefore, a perfect absorber would not radiate any energy. A blackbody spectral distribution curve can be seen in figure 2.

The basic property defining the performance of a detector is the ratio of electrical output (volts or amps) to the incident energy (watts) on the sensitive area of the detector. The central purpose of the detector is to convert the energy falling upon the detector into some electrical output. A simple infrared sensor system is shown in figure 3.

The output from the main amplifier has an amplitude proportional to the source temperature which is demodulated and registered on a meter. This meter is a signal processor that processes data collected by the sensor. Target identification algorithm stored in its memory, then determines whether or not the object in question is a real target or not. If the object is a real target, signals are sent to the actuators in the munition to direct it to impact the target.

The theory behind the infrared detector is that it should have a high sensitivity to detect energy radiating in the infrared region of the electromagnetic spectrum. It should be able to detect the hot metal on tanks and other armored vehicles that might be hidden under various forms of camouflage. These detectors measure energy at very short wavelengths, producing high photon energy, $E=hc/\lambda$. This high photon energy creates heat that can interfere with target detection. Therefore, it is necessary to reduce thermal noise which is achieved by cell cooling.

One obstacle that caused interference in infrared detection is the presence of sunlight. The means by which this problem is overcome is through the use of optical filters that are composed of semiconductor materials. Two types of semiconductor materials that are used for this application are germanium and silicon, which have a high absorption that lies below some critical wavelength. The critical wavelengths of germanium and silicon are 1.8 microns and 1.2 microns, respectively. These materials create narrow spectral responses that are free from solar and other visible background interference.

DISCUSSION

Detectors

The detector is a device that converts the radiant energy falling on its sensitive area into an electrical charge (a voltage or current). Many of these detectors function

on the properties of photoeffects in semiconductors. There are three basic interactions by which the semiconductor produces photoeffects.

1. External photoeffect--an electron is released from the surface of the semiconductive material if the energy of the photon is very great. This occurrence is also referred to as the photoelectric effect.

2. Internal photoeffect--occurs when the energy is not sufficient enough for the above to take place. In this instance, the energy is not very great, but is strong enough to produce a free electron, hole, or both. This effect is broken down into three categories:

- Photoconductive effect--measures the change in conductivity of the detection mechanism due to an increased amount of carriers in it.

- Photovoltaic effect-- a voltage is produced in the second effect when a potential barrier is created that separates the charges generated by the carriers

- Photoelectromagnetic effect--produces a voltage when the charges are separated by their diffusing action in opposite directions.

3. Heating detector material with energy generated by target radiation. The temperature of the material increased when the radiant energy is absorbed by the lattice (that makes up the material) which causes an increase in the lattice vibrational energy. Temperature directly affects the electrical conductivity of the semiconductive material. Therefore, measuring the change in conductivity is essentially measuring the change of the absorbed energy. The detector that performs this type of operation is known as a thermal detector or a bolometer. This type of detector has a negative temperature coefficient of resistivity; when the temperature increases, the resistivity decreases. Although this type of detector responds well to a wide range of wavelengths, it presents some problems. Because this element relies on the heating effect, it proves to be very slow. The response of this process can vary from 1 ms to 10 sec. Therefore, this type of detector is not recommended for use in guided munitions. By the time the detector recognizes and object as being a real target, the munition might already be out of range of the target to home in upon it.

The distinction between the photon detectors and the thermal detectors is that the photon detector measures the rate at which quanta are absorbed; whereas, the absorbed energy is measured by the thermal detectors. A quanta is the number of signal events produced per incident photon which is dependent upon wavelength.

Quantum (photon) detectors detect all incident photons with the necessary minimum energy to free a bound electron which causes them to respond to a limited range of wavelengths that are usually very short. On the other hand though, they initiate a

very fast response falling between 1 ps and 1 ms. This is marginally quicker than the thermal detectors. Therefore, in the case of a precision guided munition where a very quick response is needed, the photon detectors would be used over the thermal detectors for tracking targets. A breakdown of infrared visible photodetectors is shown in table 1.

Table. 1. Infrared-visible photodetectors

Quantum detectors	Thermal detectors
Photoconductive	Bolometers
Intrinsic	Thermistors
Extrinsic	Golay cells
	Metal
Photovoltaic	Semiconductors
PN junction	
PIN diode	Pyroelectric/ferroelectric
MES (Schottky diode)	
Heterojunctions	Thermoelectric junction
Photocapactive	
MIS/MOS photocapacitor	

Other infrared-visible detectors include phototransistors, avalanche diodes, photoemissive, and photomultipliers.

Infrared Dome Characteristics

Some of the characteristics that must be taken into account when designing infrared domes for applications in guided munitions (projectiles) are:

- Material composition of the window
- Filters to screen out unwanted data
- Optical elements
- Size and shape of the window
- Gun hardening

Since this is the material through which the infrared sensor views the environment, it must be able to:

1. Withstand bombardment from atmosphic debris to protect the sensor from mechanical damage

2. Obtain a high transmissivity (low absorption or emissivity) over the entire spectral interval to which the detector responds

3. Screen out potential interference caused by the atmosphere so that useful information generated by the source will be attained by the sensor itself.

The following is a list of specifics that must be met to enhance the performance of the munition's infrared dome.

- Low reflection and scattering losses
- Unaffected by moisture (rain, ice, snow, fog, and haze)
- Chemically stable, constant spectral transmission
- Nontoxic
- Easily shaped
- Transparent to spectrum being detected
- Low thermal radiation
- Operate at high temperatures caused by aerodynamic heating when mounted on a munition and traveling at high speeds
- Should not possess discontinuities that scatter the signal radiation
- Minimal cost to achieve desired performance

All of the previous specifications must be met in order to protect the sensitive infrared detector mechanisms from atmospheric conditions that it encounters during its flight, beginning when the munition is shot out of a gun and ending when it strikes the target. If they are not met, the system will most likely malfunction and the munition will not accomplish its desired task of destroying the enemy target.

Properties of the Atmosphere

The atmosphere is composed of a mixture of gases and particles that adversely affect the performance of infrared detection. The gases cause the radiation from the source to be absorbed by the atmosphere; whereas the particles scatter the radiation. With particles laying in the path between the source and the detector, the emitted radiation from the source can be deflected or scattered, making it appear as though the source is adjacent to the actual source itself. This can cause problems when the infrared detector is mounted in a guided munition, because the source can appear as though it is in the background. Therefore, the munition will miss its target and strike an area adjacent to the actual target.

Another problem that particles create in target detection is that they might themselves emit radiation of such a level that it may appear that they are the target. If they are not that strong but are of some significance, they can cause the path between the target and the detector to be blurry and reduce the contrast between the target and its surrounding background,

The most abundant gases found in the earth's atmosphere are nitrogen, oxygen, water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Of all of these, nitrogen and oxygen have the highest concentrations. These two gases create a phenomena called "night glow" which proves to be approximately six times as bright as starlight. The molecules that absorb the greatest amount of radiation between sea level and 40,000 ft are water molecules and carbon dioxide. The substance in the atmosphere that has the greatest adverse affect on infrared detection, is aerosol. Aerosols are composed of liquid and solid particles that are suspended by gases in the atmosphere. The absorption of these molecules is far greater than that of water vapor and carbon dioxide which, in turn, blocks the radiation emitted by the source from reaching the infrared sensor.

When designing an infrared detection system for a PGM, weather and atmospheric conditions must be taken into account. If the infrared system cannot attain its desired goals of detecting its target because of these conditions, other spectral sensors must be added to the munition's sensing system to make it more reliable. In the following section, two types of enhancements are offered to compensate for weaknesses found in infrared detectors.

Enhancements to the Detector System

The greatest weakness in infrared detection is the effects of adverse weather conditions and the composition of the earth's atmosphere. One means by which this problem can be overcome is by incorporating another type of detector system that

responds to a different wavelength to enable the guided munition to function properly in the instances where the infrared detector encounters inclement weather and atmospheric conditions.

This method of incorporating two detector systems in a single precision guided munition is called multimode or dual mode sensing. This method could combine a passive mode with an active mode (or another passive mode, or two active modes, or semi-active mode) in a single munition. As mentioned earlier, the passive mode used energy emitted by the target itself, or reflected off of the target, for tracking. In the active mode, the target is illuminated by a beam of energy from the carrier that is reflected by the target and provides a strong enough signal to be tracked by the seeker in the munition. This mode is used when the radiated signal from the target is too weak to be detected by the munition sensor. By illuminating the target with energy emitted by a sensor located on the munition, the energy radiating from the target will be increased so that the target can be detected. This process could be achieved by using a radar system in the munition.

Multispectral guidance, one type of multimode detector system, operates by employing two or more wavelengths to track the target. Some examples of this type of system are infrared and RF, dual frequency RF, two-color infrared (used to avoid fires and flares), or infrared and ultraviolet (which is rarely used). This system reduces the effects that countermeasures have on tracking systems, increases the accuracy, increases target detectability, decreases false alarms, and is not very susceptible to inclement weather conditions.

Implementing two detectors that operate at different wavelengths enables the PGM to track a target successfully over a much larger array of obstacles.

CONCLUSIONS

Implementing infrared detectors (IR) into artillery delivered munitions greatly increases the probability of striking designated targets on the first shot. By only firing once at a target to destroy it, the operating personnel can then move on to fire upon other potential targets. IR guided munitions provide the operating personnel with a distinct advantage over the conventional artillery shells, and enables our military to conduct combat missions even at night.

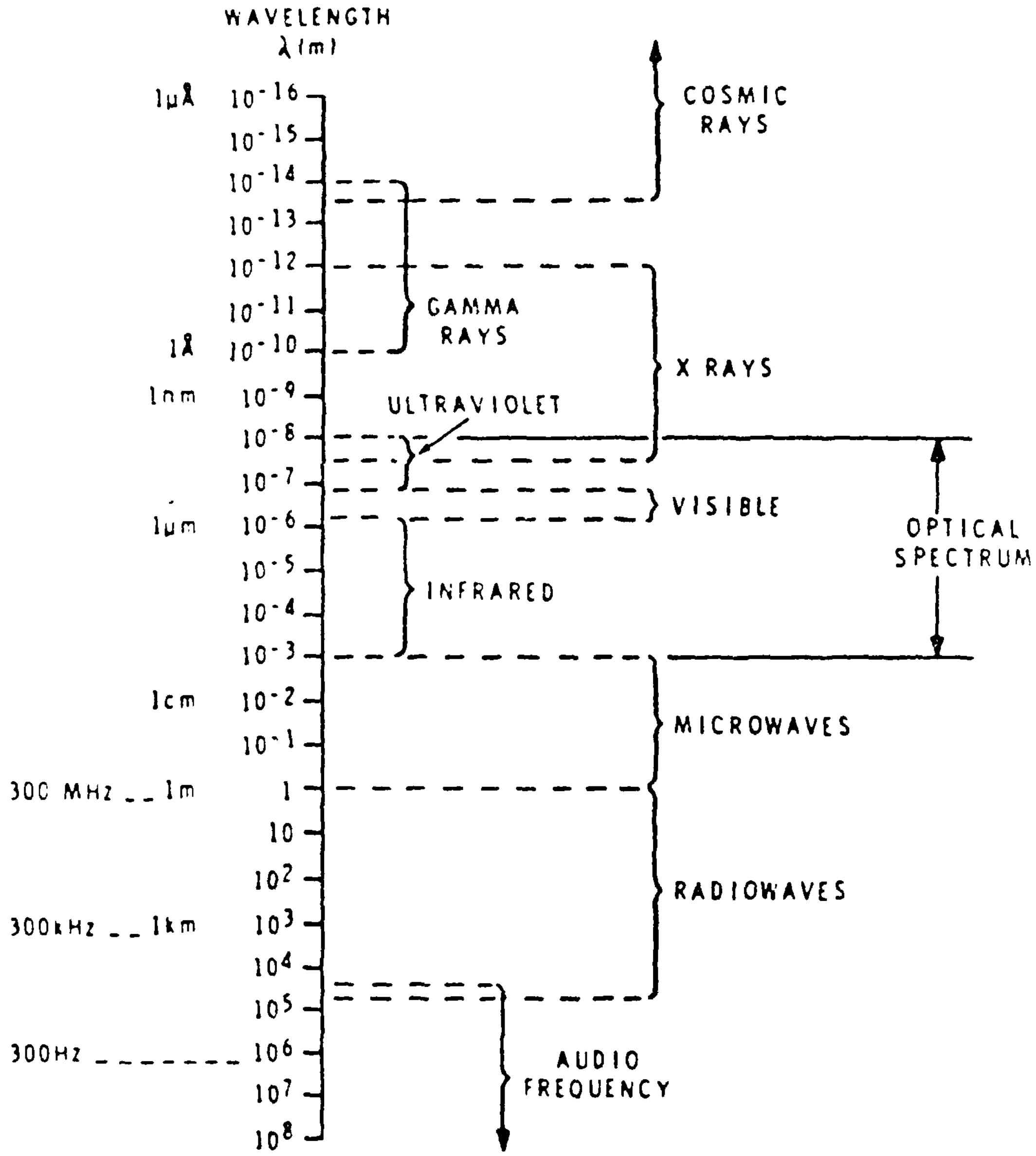

Figure 1. Electromagnetic spectrum

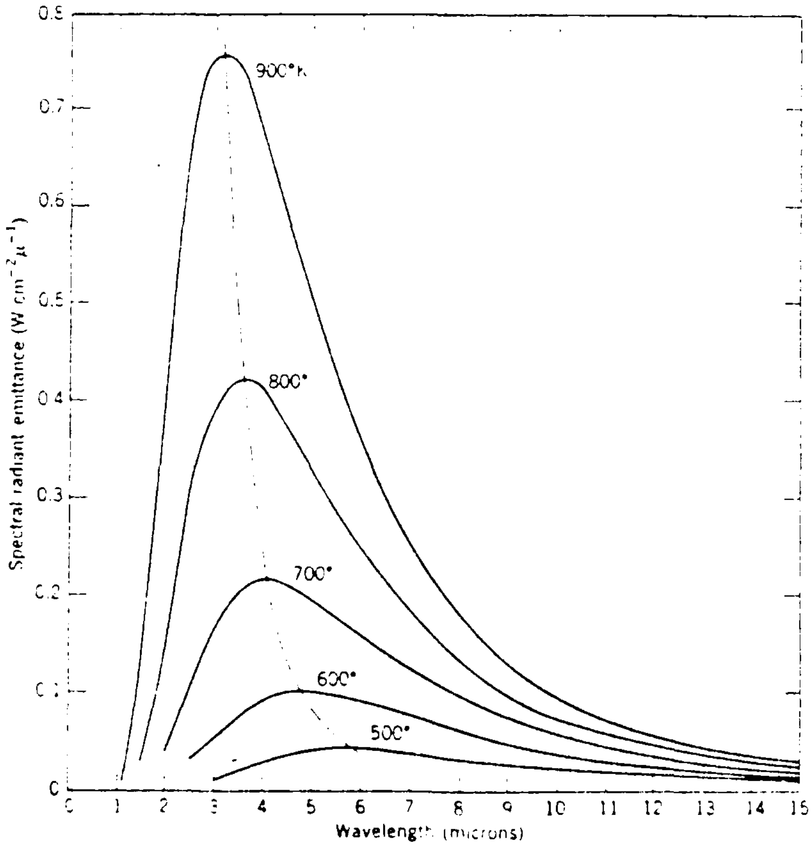

Figure 2. Blackbody spectral curve

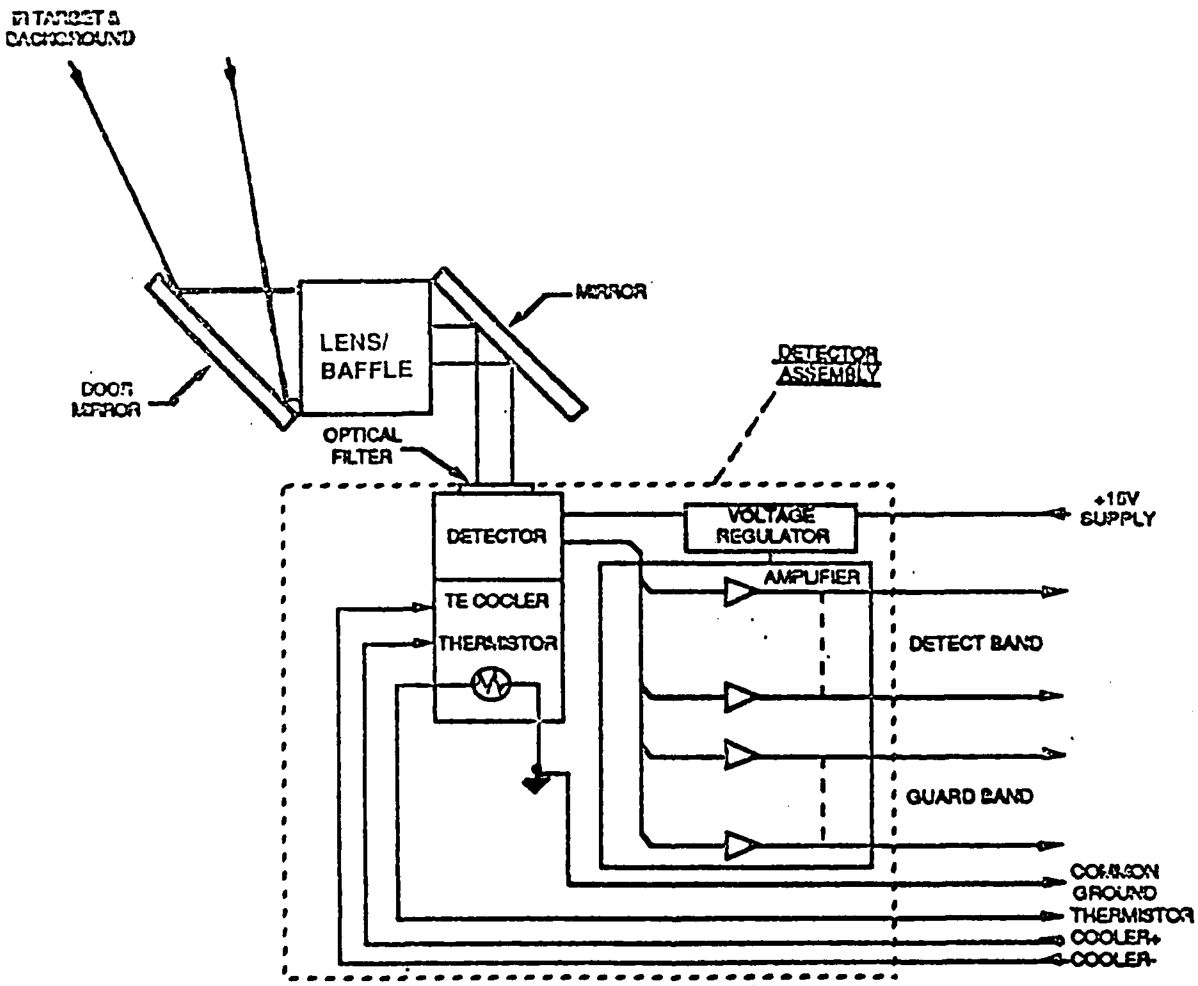

Figure 3. Simple infrared sensor system

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